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The Role of Task Difficulty in Learning a Visuomotor Skill

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Abstract

Introduction: Task difficulty affects the amount of interpretable information from a task, which is thought to interfere with motor learning. However, it is unclear whether task difficulty in itself is a stimulus for motor learning because the experimental evidence is mixed in support of the optimal challenge point framework that predicts one specific level of task difficulty to produce the greatest magnitude of motor learning.

Purpose: We determined the effects of functional task difficulty on motor skill acquisition, retention, and transfer.

Methods: Healthy young participants ($N = 36$) learned a mirror star-tracing task at a low, medium or hard difficulty level defined by the bandwidth of the star. We measured skill acquisition, retention and transfer to untrained difficulty levels, as well as the perceived mental workload during the task.

Results: Task difficulty affected motor performance, but did not affect motor learning and transfer. For the groups that practiced the task at the medium and hard but not at the low difficulty level, initial skill level correlated with the magnitude of learning.

Conclusion: The optimal challenge point framework does not capture the complex relationship between task difficulty and motor learning. Previously reported effects of task difficulty on the magnitude of motor learning are probably mediated by perceived mental workload. Task difficulty did not affect the magnitude of visuomotor skill learning but it affected how learning occurred. The data have implications on how athletes learn new motor skills and patients re-learn injury-impaired motor skills during rehabilitation.

Keywords: Motor Learning; Motor Control; Challenge Point; Error-prone Learning; Errorless Learning; Mental Workload

Introduction

Motor learning is important during the lifespan and can be defined as “a problem-solving process in which the goal of an action represents the problem to be solved” (1). To solve this problem, the performer selects the most suitable action plan from the many available options and ‘learns’ the task. Sources of information available during and after each attempt to perform the task help pick the right action plan and this information forms the basis of motor learning (1–3). Based on Fitt’s law, the amount of interpretable information derived from a task depends on the difficulty of the task (4).

Task difficulty is a broad concept and can be seen as a summed manifestation of all task characteristics (4,5). A task is difficult if it cannot be mastered in a single session and has multiple degrees of freedom (6). With increasing task difficulty, the number of errors tends to increase. The information content embedded in the errors shapes the action plan and helps to improve performance. However, our information capacity is limited and when exceeded, the performer chooses an incorrect action plan and errors and poor performance ensue (2,4,7). High task difficulty can lead to information overload, which is thought to interfere with motor learning (1,4).

The central tenet of the optimal challenge point framework is this information processing underlying motor learning. The framework posits that a specific level of task difficulty produces the greatest magnitude of motor learning. This level is called the optimal challenge point and depends on two types of task difficulty: nominal and functional. Nominal task difficulty is the difficulty provided by the task independent of the individual and environmental constraints, whereas functional task difficulty refers to the challenge level of the task for the person performing the task. Functional task difficulty is therefore not only influenced by nominal task

difficulty, but also by the skill level of the performer and the environment in which the task is performed (1).

Since the introduction of the optimal challenge point framework, most experiments to test its assumptions have been based on the effects of external manipulations of functional task difficulty on motor learning, for example by manipulating practice schedules (8–11). Little is known about the relationship between functional task difficulty and motor learning when functional task difficulty is mainly driven by the nominal difficulty of a task. The framework predicts that motor learning increases up to a certain level of nominal task difficulty, beyond which further increases in difficulty are counterproductive and learning does not improve and can in fact deteriorate (1).

However, the experimental evidence is mixed for the presence of an optimal level of nominal task difficulty. In a postural control task, the optimal challenge point occurred at a medium difficulty level. Difficulty in this task was manipulated by changing the stability of the ground surface (12). In a sequence key-press task, where difficulty was manipulated by the information given about the next key, the most difficult level corresponded to the optimal challenge point. However, there are also studies reporting no optimal point of task difficulty. In a tracing task, the bandwidth represented task difficulty and affected warm-up decrements, but not the rate of improvements (13). In a dart-throwing task, motor learning was also independent of difficulty level, i.e., target size (14).

Individual differences as well as differences in difficulty manipulations between studies can underlie these inconsistencies. Most studies attempted to control for individual differences by implementing novel tasks and doing group-level analysis. However, the challenge point framework as well as recent work emphasize that individual characteristics affect the

experienced difficulty level (1,15). Although the amount of available information from a task is directly related to nominal task difficulty, the amount of interpretable information also depends on individual characteristics such as initial skill level and the capacity to process information (16,17). Therefore, a task with a medium level of nominal task difficulty can be easy for someone with a high initial skill level, while someone with a low initial skill level can experience the task as hard. In addition, since there is no unifying definition of task difficulty, most studies quantify nominal task difficulty in terms of performance outcomes, e.g. longer movement times or higher error scores with increasing difficulty. However, different tasks are difficult to compare and expressing it this way, a level of difficulty that is hard in one task can correspond to a level of difficulty that is medium or easy in another task. In addition to the nominal task difficulty, the functional task difficulty should be also taken into account. Recently, the measure of mental workload through the National Aeronautics and Space Administration Task Load Index (NASA-TLX) has been put forward as a subjective measure of functional task difficulty (12,15,18). Designed to measure mental workload in pilots, the NASA-TLX is a valid index of mental workload in a variety of contexts, including motor learning (19).

Beyond the magnitude of improvement and the perceived workload, the magnitude and direction of transfer are behaviourally also relevant measures of motor learning. Transfer is the conveyance of the learned skill from one to another difficulty level. Until now, experimental evidence favours no particular direction of transfer (20). Based on the optimal challenge point framework, it is expected that transfer from a hard to an easy task is greater than from an easy to a hard task (1). In reaching, where difficulty was defined as distance to the target and transfer was defined as performance on a target distance not included in the acquisition phase, this

expectation was indeed confirmed (10). However, in a stick balancing task, transfer from an easy to a more difficult task was more beneficial than the other way around (11).

Altogether, experimental evidence is mixed and inconclusive in support of an optimal challenge point for motor skill learning. Because athletes are constantly on the lookout to increase training effectiveness, a better understanding of how functional task difficulty can be measured and how it affects motor learning can improve the efficacy of training protocols. If an optimal challenge point indeed exists, training at the optimal difficulty level would increase the effectiveness of training and decrease learning time. In addition, patients in rehabilitation would likely recover functions impaired by an injury faster and to a greater extent if they practiced the impaired function at the optimal difficulty level. Using a reductionist approach, we implemented a new visuomotor mirror-star tracing task in a homogeneous population (healthy young adults). In this task, we measure performance in terms of speed and accuracy. Using this approach, nominal task difficulty is the key determinant of functional task difficulty, while still taking individual differences into account.

The purpose of this study was to determine the effects of functional task difficulty on motor skill acquisition, retention, and transfer. Based on the optimal challenge point framework, we tested three hypotheses: 1) motor skill practice at a medium or hard versus a low difficulty level of the same task will produce greater motor skill acquisition and retention in terms of speed and accuracy, 2) the learning benefit gained from a specific difficulty level depends on the initial skill level as predicted by the optimal challenge point framework, and 3) motor skill transfer is difficulty-dependent so that the optimal direction of transfer is from hard to easy.

Methods

Participants

Healthy and right handed (21) young adults aged 18-30 years ($N = 36$; 38.9 % male; age: 22.97 ± 2.43 years; height: 175.67 ± 9.97 cm; weight: 68.44 ± 13.61) participated in the study. Exclusion criteria were the use of medication that affects neural functioning, movement restrictions with and pain in the right hand or arm, presence of a neurological condition and familiarity with the task. Participants gave written informed consent to the study protocol, which was approved by the ethical committee of Human Movement Sciences at the University Medical Centre of Groningen.

Design

Participants were randomly assigned to one of three groups based on the nominal difficulty of the motor skill they subsequently practiced: Motor Practice with Low Difficulty (P-LD), Motor Practice with Medium Difficulty (P-MD) or Motor Practice with High Difficulty (P-HD). Participants visited the lab on two consecutive days. On Day 1, visuomotor performance was measured (baseline), followed by motor practice at the assigned difficulty level for 160 trials. After practice, the post- and transfer tests were administered. Participants also rated how difficult they perceived the execution of the motor skill using the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (18). On Day 2, ~24 h after practice, the baseline and transfer measurements were repeated to quantify skill retention.

Task

Based on pilot experiments, we adopted and modified the star-tracing task (22,23). The modifications compared with previous studies consisted of: 1) performing the task on a 24 by 16.95 cm Apple iPad Air; 2) visualizing the iPad surface through a mirror to make the task even more challenging, and 3) creating three levels of tracing difficulty by changing the bandwidth of the star (13). Participants sat in a chair and placed both hands on the surface of a table in front of them. The iPad was placed on the table top in front of the participant. The task was to trace, by holding a stylus in the right-dominant hand, a symmetrical pentagon-shaped star as fast and accurately as possible. Participants looked at their moving hand in a mirror placed vertically 14 cm beyond the back edge of the iPad. A sheet of cardboard placed horizontally above the participant's hand and below the chin, prevented participants from seeing the hand tracing the star. The length of each of the five sides of the pentagon was 10.5 cm. The width of the wall of the star was set to 3 (Hard Difficulty, HD), 5 (Medium Difficulty, MD), or 7 mm (Low Difficulty, LD). Participants were instructed to trace the star by moving the stylus within the bandwidth formed by the walls of the star. The non-dominant left hand rested on the table next to the iPad. Fig 1 shows the setup. While executing the task, the star was visible to the participant and a blue dot represented the start and end point of the tracing path. When ready, the participant was asked to place the stylus on the blue dot, after which a beep signalled the start of the trial. Because frequency of knowledge of results (KR) and knowledge of performance (KP) can affect motor performance and learning (24,25), KP was available during each trial by maintaining visibility of the star. In addition, KR was kept at 100% for each group, by presenting the movement time and error percentage after each trial. Before the start of the test, participants familiarized themselves with the task by performing one trial at each difficulty level. For the pre-

, post- and retention tests, participants traced the star at the assigned difficulty level 10 times. Motor practice consisted of four blocks of 40 trials at the assigned difficulty level. Transfer was quantified as performance at the untrained difficulty levels, comprising ten trials each. The order of the difficulty levels in the transfer task was block randomized across participants.

NASA-TLX

The NASA-TLX was administered at the end of Day 1, using the official NASA-TLX IOS application on the iPad. Participants rated six dimensions related to perceived effort completing the motor task with their assigned difficulty on a scale from 0 to 100: Mental demand, Physical demand, Temporal demand, Performance, Effort and Frustration. In addition, to determine the weighting of each dimension, participants completed pairwise comparisons across all pairs of the six dimensions. Weightings were given to each dimension based on the number of times a dimension was chosen as most relevant. Total workload scores were computed by multiplying the weighting with the rating score of each dimension, summing the scores across all dimensions and dividing by 15 (18).

Data analysis

Visuomotor data were analysed with custom made Matlab scripts (The Mathworks, Natick, Massachusetts, USA, version R2016b). Raw position data were manually checked for correctness before interpolating at 60 Hz. Because participants at times made large errors unrelated to motor performance at the start and end of a trial, these initial and final segments were excluded from the analyses. Visuomotor performance was quantified as the error percentage and movement time per trial, in order to capture both speed and accuracy.

Movement time was defined as the time it took for participants to complete the full path of the pentagon one time. Error percentages were computed as the percent of samples outside of the bandwidth (S_{error}) per trial (total samples S_{total} : 660 ± 346), according to the equation:

$$\% \text{Error} = (S_{\text{error}}/S_{\text{total}}) \times 100 \quad [1]$$

In addition, to allow a better comparison between groups the total distance of the traced path per trial was calculated as an accuracy measure that was independent of the bandwidth manipulation.

Statistical analyses

All data were analysed with IBM SPSS Statistics version 23. Data were first checked for normality using the Shapiro-Wilk test. If the data was not normally distributed, a log transformation was performed. Missing values were replaced with mean substitution. On average, missing values constituted 3.9% of the data. To check if the difficulty manipulation was successful, separate repeated-measures ANOVAs were done for error percentage, movement time and total distance as dependent variables on baseline scores with all participants grouped across difficulty levels as the within-subjects factor. To check hypothesis 1, i.e., task difficulty affects motor skill acquisition and retention, separate Group (P-LD, P-MD, P-HD) by Time (pre-, post and retention) ANOVAs were used with repeated measures on Time for error percentage, total distance and movement time as dependent variables. To examine the impact of individual differences in initial skill level on motor learning and retention, i.e., hypothesis 2, Pearson correlations were calculated between the scores on the pre-test and the improvement on the post- and retention-tests for movement time and total distance. We tested hypothesis 3, i.e., task difficulty affects transfer to unpractised tasks, by a Group (P-LD, P-HD) by Time (immediate, delayed) ANOVA with repeated measures on Time for error percentage, total distance and

movement time on the unpractised MD-test as dependent variables. Only the P-LD and P-HD groups are taken into account here to allow a direct comparison in performance on an unpractised task between two different directions of transfer. For all ANOVAs, a Greenhouse Geisser correction was performed when the assumption of sphericity was violated. Post-hoc tests were performed using Tukey's HSD. To check for any differences between the NASA-TLX scores for the different groups, an one-way ANOVA was performed on the raw ratings of all the subscales and the total workload score. For all analyses, the significance level was set at $\alpha = 0.05$.

Results

Motor performance

At baseline, there was a significant main effect of difficulty for both error percentage ($F(2,70) = 323.9, p < .001$) and movement time ($F(2,70) = 9.4, p < .001$), confirming that the width of the wall of the star created a task difficulty effect in terms of performance (Fig. 2). Post hoc comparisons revealed that error percentage during the execution of the HD task was 20.3% higher than during the MD task and 32.9% higher than during the LD task and that the error percentage in the MD vs. the LD task was 12.7% higher (Fig. 2A). During the HD task, movement time was 14.7% longer than during the MD task and 22.0% higher than during the LD task (Fig. 2B). Task difficulty did not affect the total distance of the path (Fig. 2C, $F(2,70) = 0.8, p > .05$). There was no task difficulty effect in terms of mental workload, measured as global outcome or on the six subscales of the NASA-TLX (see Table, Supplemental Digital Content 1, <http://links.lww.com/MSS/B264>, NASA-TLX scores).

Motor learning

Practice improved motor performance in all groups (Time main effect) as measured by total distance ($F(1,52) = 9.6$, $p = 0.001$) and movement time ($F(1,33) = 5.2$, $p = 0.029$, Figs. 3B-C), but no improvement was seen in error percentages ($F(2,66) = 30.6$, $p = 0.241$, Fig. 3A). There were no group by time interactions for either outcome. Movement time at pre-test correlated with improvements at both post- and retention tests (Table 1). For total distance, performance at pre-test did not correlate with improvements at post- and retention tests when the difficulty was low (Table 1), although 10 out of 12 subjects improved their performance (Fig. 4A). Performance at pre-test did correlate with improvements at post-test when the difficulty was medium or high (Table 1) but the distribution of the scores underlying the correlations was the opposite: at medium difficulty, 4 of 12 subjects improved whereas at high difficulty 9 of 12 subjects improved (Figs. 4B-C). There was only a correlation between total distance at the pre-test and improvement at the retention-test when the difficulty was medium (Table 1).

Transfer

To examine the direction effects of transfer to untrained levels, scores for immediate (directly after practice) and delayed (24 h after practice) transfer from the P-LD and P-HD groups to the MD-task were compared. The groups did not differ in their performance on the MD-task for error percentage ($F(1,22) = 0.4$, $p = 0.554$), total distance ($F(1,22) = 0.3$, $p = 0.569$) and movement time ($F(1,22) = 1.1$, $p = 0.304$).

Discussion

We determined the effects of task difficulty on motor skill acquisition, retention, and transfer. Task difficulty did not affect the magnitude of visuomotor skill learning but it affected how learning occurs. Practicing a mirror star-tracing motor task at three levels of difficulty affected motor performance in terms of error percentage and movement time, but motor skill acquisition, retention and transfer to untrained difficulty levels were independent of task difficulty. Task difficulty also did not affect the perceived mental workload as measured by the NASA-TLX. Unexpectedly, initial skill level only influenced skill acquisition and retention when practicing at a medium or hard difficulty level. We discuss these findings with a perspective on the optimal challenge point framework for motor skill learning.

The data did not support hypothesis 1: task difficulty did not affect the magnitude of visuomotor skill learning, measured immediately and 24 h after motor practice (Fig. 3). Based on the challenge point framework, we expected that practicing the star-tracing task at a medium or high compared with low difficulty level would have afforded learning benefits. Despite a clear effect of task difficulty on motor performance at pre-test (Figs. 2A-B), the magnitude of skill acquisition and retention were both independent of task difficulty. Previous studies suggested a putative role for mental effort in the effects of task difficulty on motor learning by reporting correlated increases in mental workload and motor learning (12,15). Clearly, this was not the case in the present study, as perceived mental demand did not differ between difficulty levels (Supplemental Digital Content 1, <http://links.lww.com/MSS/B264>). Although we gave feedback to participants about the time and accuracy for the trial they just completed, seeing the star during tracing gave participants the opportunity to extract knowledge of performance as an extra

source of information. That is, they could simply aim at the middle of the star wall and disregard the knowledge of results we provided on time and accuracy (26). Regardless of difficulty level, aiming at the middle of the star wall is always an effective strategy which we suspect subjects themselves discovered. Therefore, this knowledge of performance may have dominated over the knowledge of results provided at the end of a trial in the form of movement time and error percentages. A lack in improvement in the error percentages further support the possibility that participants ignored those percentages and instead aimed for the middle of the star wall (Fig. 3A). A similar phenomenon occurred in a dart-throwing task, where task difficulty was manipulated by manipulating target sizes. In this task, visual feedback also provided participants with the possibility to aim for the middle of the target and task difficulty did not affect motor learning (14). Because of the availability of this concurrent knowledge of performance during tracing, movement slowing with increasing difficulty in the current task may be a mechanism to minimize mental workload (Fig. 2B). Movement slowing is probably related to an increase in the time needed to generate more detailed motor plans and process afferent feedback with an increase in demand for accuracy. Movement slowing can provide participants with extra time to interpret the increasing amount of task-relevant information when the bandwidth is narrow and more errors are made, which can reduce the perception of task difficulty in terms of information flow (4).

The optimal challenge point framework suggests that in addition to nominal task difficulty, individual characteristics can also affect motor learning. One important individual factor is the ability to process information, which varies widely between individuals (15–17). In a reaching task with two levels of nominal difficulty, a cluster analysis revealed that more pronounced

individual variations in mental workload and performance occurred with increasing nominal task difficulty (15). The current results also show high variability within groups as well as in the magnitude of learning. These results highlight the mediating role of mental workload in the effects of task difficulty on motor learning, which could be confirmed by measuring brain activity. Correlating changes in brain activity and changes in motor performance could disentangle the relationship between individual information processing capacities, mental workload and motor learning.

Although task difficulty did not affect the magnitude of learning, it did affect the way learning occurred. High correlations between performance on the pre-test and the amount of improvement in the P-MD and P-HD groups underscore the influence of functional task difficulty on motor learning (Figs. 4A-B). In these two groups, participants with the lowest initial skill levels improved the most, which is in line with the optimal challenge point framework. Because participants in these groups made a lot of corrections during tracing, indicated by a high total distance, the potential was high to extract learning-relevant information. By using the strategy of movement slowing described above, participants benefited from these errors without overloading their information processing capacity. The interaction between initial skill level and nominal task difficulty is seen in the different distributions of the individual scores forming the correlations in the two groups. The P-MD compared with the P-HD group produced fewer errors and therefore a longer total distance in the beginning - corresponding to a lower initial skill level - was necessary in order to improve, so that only 4 of 12 participants in this group improved motor performance (Fig. 4B). In contrast, in the P-HD group almost all, 9 of 12, participants improved, suggesting that participants with a higher initial skill level still benefited from practicing at the most difficult

level (Fig. 4C). This analysis tentatively suggests that practicing an unfamiliar motor task at high vs. lower difficulty levels could produce greater magnitudes of motor learning and supports the challenge point framework.

When performing the easy (LD) task, participants made few errors (Fig. 2A). As reasoned by the challenge point framework, only participants with a very low initial skill level would make enough errors to benefit from practice with the easy task. However, unexpectedly the initial skill level in the P-LD group was unrelated to improvement at the post-test, while still almost all, 10 of 12, participants in this condition improved their performance (Fig. 4A). Therefore, improvement in this group must be mediated by some other approach than error detection. Recently, studies that minimized error during motor practice show the benefit of learning without errors (errorless learning) (28–30). In errorless learning participants rely on feedback minimally, resulting in the evolution of implicit learning. This learning is robust because the memory traces are more resistant to interference and stress in particular.

A comparison between the present and past data raise the hypothesis that mental instead of motor effort mediate the previously reported effects of task difficulty on motor learning (12,14,15,27). Results from the current study suggest that not nominal task difficulty, but the effect of task difficulty on mental workload affects motor learning and that the optimal challenge point framework is only applicable when a certain amount of error is present. If participants make enough errors, they put effort into processing the information arising from those errors and use this information to improve. However, against the framework, when the available information from a task is insufficient, participants are still able to improve by adopting a more implicit type

of learning. In addition, if a manipulation of difficulty is used where it is possible to minimize the effect of difficulty on mental workload, for example by moving slowing or generating more objective feedback, the effects of task difficulty on motor learning seems to be minimal (13,14). Future work is needed to confirm this hypothesis and determine the relationship between mental workload, errors and the difficulty level used in practicing a motor skill.

Assuming that the improvement in the P-LD and P-HD groups are indeed mediated by different underlying approaches, comparing their performance on an unpractised difficulty level would allow us to compare directly between learning from errors (error-prone learning) and errorless learning. However, when tested on the unpractised medium level MD-task, learning using an easy and a hard task produced similar magnitudes of transfer. The transfer and the practice tasks were rather similar, a phenomenon defined as 'near transfer' (31). The relationship between difficulty of the motor task and transfer seems to depend on the distality of the transfer test: similarity of the transfer and practice task reduces the effects of task difficulty on transfer (10,31). However, it is not clear how error-prone vs. errorless learning influence this relationship. Therefore, further research should increase the dissimilarity between practice and transfer task and compare learning with errors vs errorless learning.

This study has several limitations. First, by having participants trace the star as rapidly and as accurately as possible, we increased variation in motor performance as participants could practice at any point along the speed-accuracy trade-off continuum (32). Therefore, future studies should develop a composite outcome, comprising both speed and accuracy. Second, we only considered performance of participants before and after learning, while ignoring the rate of

improvement in performance during practice. Although absolute improvements between groups did not differ, there is a possibility that there is a difference in learning rates, which could give further insights into differences between error-prone vs. errorless learning. Had we increased practice time in tandem with task difficulty, it is possible that each group would have reached its learning asymptote at a different time, producing a hierarchical learning pattern according to task difficulty. While keeping a broad perspective, a further limitation is that we did not apply the current experimental conditions to athletes needing to learn a new skill or to individuals undergoing rehabilitation who need to re-learn a skill impaired by an injury. Our data imply that highly capable athletes may benefit by practicing a new skill at high difficulty and patients re-learning a 'lost' skill would progress more effectively if practicing under conditions with a lower difficulty level.

In conclusion, the current results suggest that the optimal challenge point framework does not fully capture the complex relationship between task difficulty and motor learning. It seems likely that the effects of task difficulty on motor learning as predicted by the framework are mediated by mental workload and that the framework is only applicable when a certain amount of errors is present. While applicable to explain the variations in the P-MD and P-HD groups, the framework fails to explain the results of the P-LD group. Contrary to the framework, we found that magnitude of motor learning in an easy task is independent of the available information. For motor skill acquisition, retention and near transfer the current results suggest that both learning with and without errors is equally effective. Task difficulty did not affect the magnitude of visuomotor skill learning but it affected how learning occurred.

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Conflict of Interest and Source of Funding

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Figure Captions

Table 1

Pearson correlations between scores on the pre-test and improvements immediately (post-test) and 24h (retention-test) after learning for the three groups separate.

Fig. 1

Experimental set-up of the mirror star-tracing task. Participants traced the star as fast and accurately as possible with a stylus, while staying within the bandwidth. The sheet of cardboard prevented participants from directly seeing their hands, so they could only look at their moving hand through a mirror.

Fig 2.

Baseline differences between tasks for error percentage (A), movement time (B) and the total distance of the path (C) (N = 36). Error bars represent standard error. ** $p < .01$, *** $p < .001$.

Fig 3.

Improvement in motor performance of the three groups relative to the pre-test, quantified by error percentage (A), movement time (B) and total distance (C). Errors bars represent standard error.

Fig 4.

Correlation between scores on the pre-test and improvement at the post-test for the total distance of the path for the three groups separate

Supplemental Digital Content

Supplemental Digital Content 1. Table that provide the NASA-TLX scores. doc

ACCEPTED

Figure 1

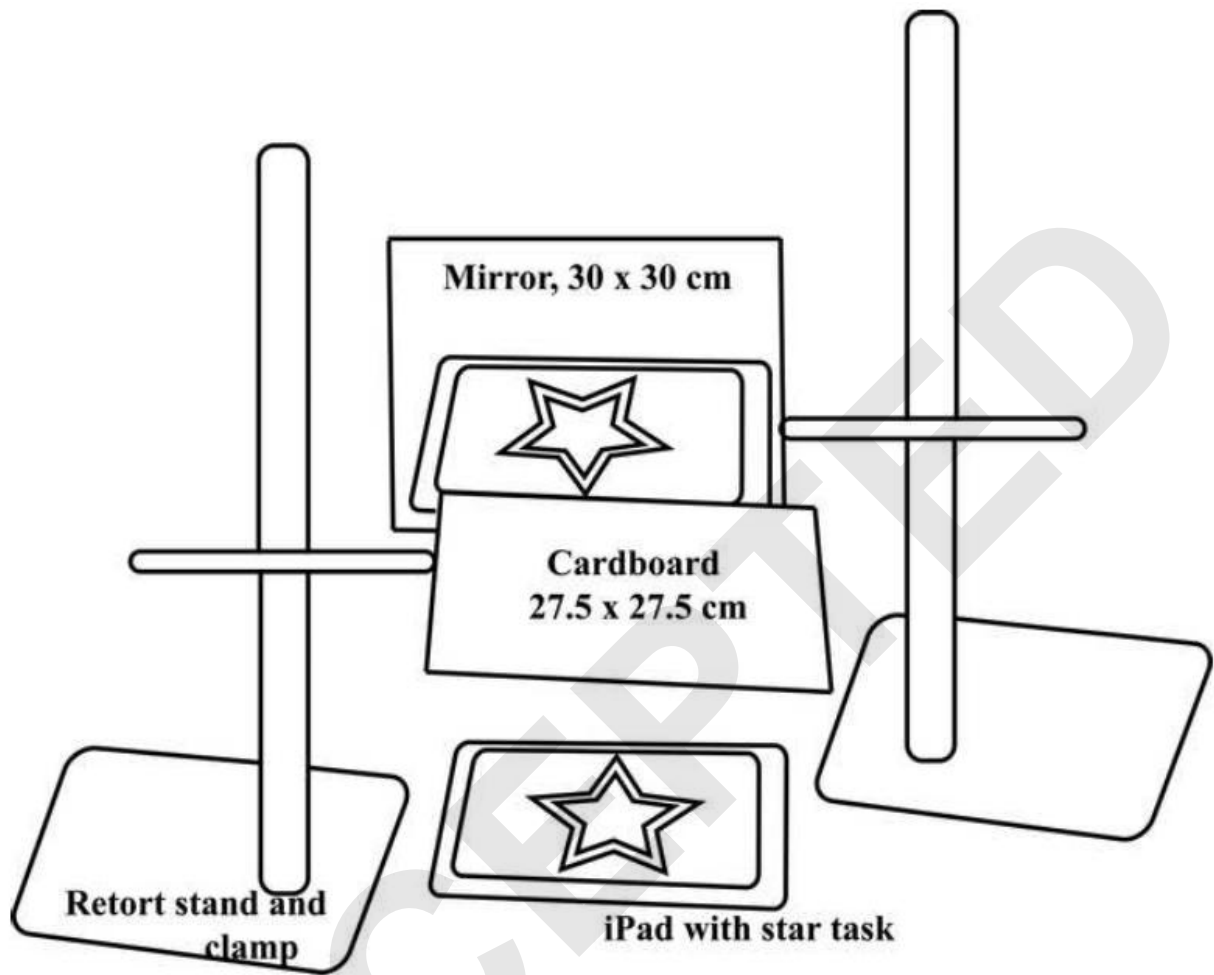


Figure 2

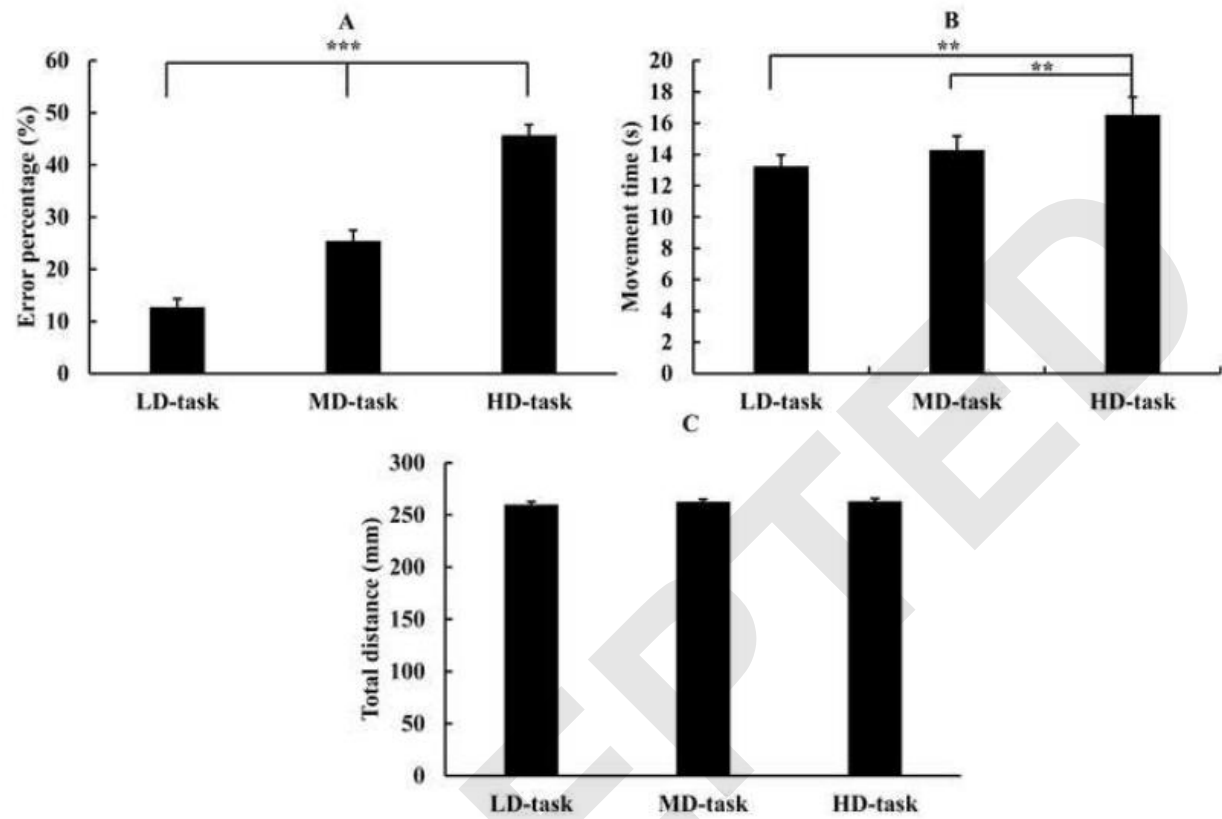


Figure 3

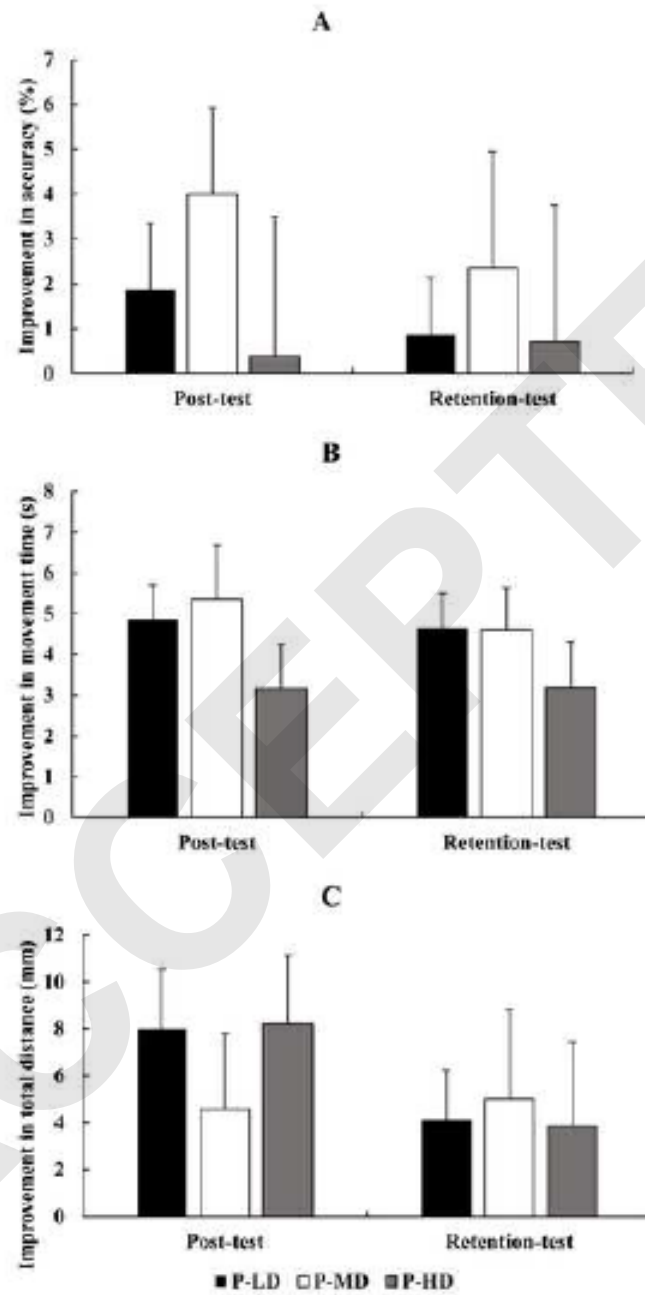


Figure 4

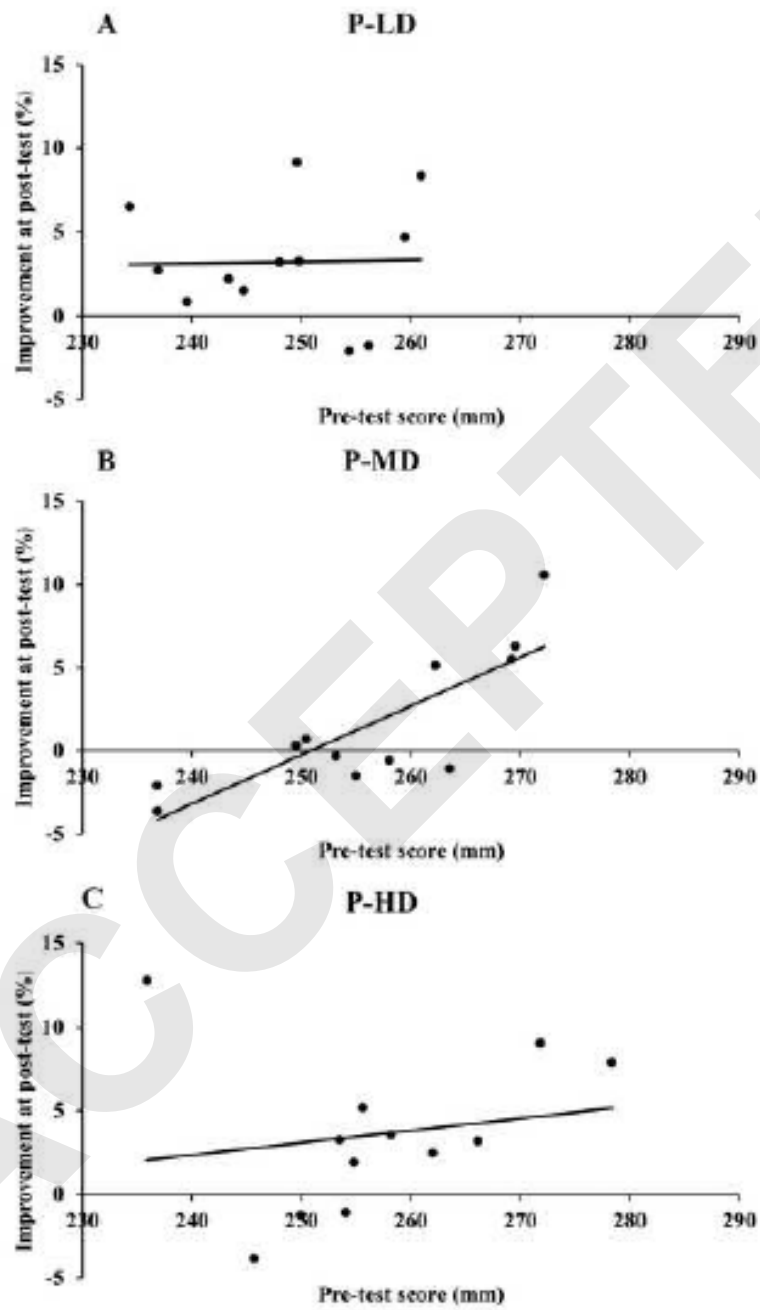


Table 1. Pearson correlations between scores on the pre-test and improvements immediately (post-test) and 24h (retention-test) after learning for the three groups separate.

	Improvement Post-test		Improvement Retention-test	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Pre-test scores				
<i>Movement time</i>				
P-LD	0.80	0.002	0.83	0.001
P-MD	0.87	< 0.001	0.84	0.001
P-HD	0.71	0.009	0.61	0.04
<i>Total distance</i>				
P-LD	0.023	0.9	0.18	0.6
P-MD	0.82	0.001	0.82	0.001
P-HD	0.85	0.001	0.53	0.08

Supplemental Digital Content 1. NASA-TLX scores

	P-HD	P-MD	P-LD
	(Mean ± SD)	(Mean ± SD)	(Mean ± SD)
Subscale			
Mental demand	62.5 ± 21.58	61.3 ± 22.17	67.5 ± 18.40
Physical demand	39.2 ± 26.44	27.1 ± 21.05	38.3 ± 21.67
Temporal demand	47.9 ± 23.69	46.7 ± 19.11	51.3 ± 22.07
Performance	52.1 ± 20.61	38.3 ± 16.28	38.8 ± 20.24
Effort	59.6 ± 22.31	53.8 ± 16.80	67.1 ± 10.76
Frustration	50.0 ± 32.89	38.8 ± 28.29	45.4 ± 20.83
Total Workload	58.4 ± 15.63	49.6 ± 13.17	56.5 ± 6.17